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Effects of Acidification on Benthic Fauna in St. Marys River, Augusta County, Virginia

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INTRODUCTION

The impacts of acidification on aquatic organisms have been well documented in the literature (Magnunson, 1983). Griffith & Perry (1992) summarized the literature on the effects of acidification on benthic invertebrates and reported that acid sensitive species decline in abundance, acid tolerant species increase in abundance, number of species decline, and community biotic diversity decreases. Three primary methods have been utilized by researchers to assess biotic changes from acid deposition: experimental acidification, spatial comparisons between geographically similar waters with differing water chemistry, and temporal comparisons of a resource. Temporal comparisons, however, are rarely documented due to the lack of long-term data sets.

Documented biological changes due to acid deposition in invertebrate communities have been limited to northern states, Canada, and Scandinavian countries. This is expected since these areas are considered more sensitive to acidification due to loss of soils from glaciation. Despite the lack of glaciation, waters in southern states are sensitive because of their underlying geology and streams with low acid neutralization capacity have been documented (Herlihy et al., 1993). Lasier (1986) was unable to document any biological impacts to southern streams due in part to the lack of historical data.

The St. Marys River in Virginia provides the opportunity to temporally assess the impacts of acid deposition on a southeastern USA stream. Historic invertebrate and water chemistry data exist from 1936 and 1937 (Surber, 1951). Recent invertebrate data have been collected by Virginia Department of Game and Inland Fisheries (VDGIF) personnel starting in 1976 as part of the Virginia trout stream survey. The historic data from Surber and VDGIF provide a unique opportunity to compare reliable invertebrate data on an acidified stream drainage over a 60-year time span. The stream was once a premier wild trout stream but has been degraded by the impacts of anthropomorphic acidification (Webb & Diviney, 1999).

STUDY AREA

St. Marys River is a third order coldwater stream that drains the west slope of the central Blue Ridge Mountains in southeastern Augusta County, Virginia. It forms the southwest boundary of the Big Levels Management Area and its 27 km^2 watershed is the centerpiece of the 4,000 hectare St. Marys Wilderness Area. St. Marys River originates at 951 m above sea level and descends at a gradient of 39 m/km to its confluence with Spy Run, 11.4 km downstream.

The watershed is comprised of five major tributaries (Fig. 1). St. Marys River's low ANC levels can be traced to the geologic formations that underlie the watershed (Webb & Diviney, 1999). Antietam quartzite is the primary rock formation (Werner, 1966). Formations of Hampton quartzite underlie the upper watersheds of Sugartree Branch, Mine Bank Creek, Bear Branch, and Chimney Branch, as well as the lower reach of St. Marys River. Both formations are known to have low solubility in water, thus providing few reactive materials to neutralize acidic input (Webb & Diviney, 1999).

Dominant overstory vegetation in the St. Marys River basin include chestnut oak (*Quercus prinus*) and scarlet oak (*Quercus coccinea*) on ridges and north aspects, with pitch pine (*Pinus rigida*) and table mountain pine (*Pinus pungens*) dominating the southern and western slopes. Understory plants include mountain laurel (*Kalmia latifolia*), bear oak (*Quercus ilicifolia*), rhododendron (*Rhododendron maximum*), dogwood (*Cornus florida*), red maple (*Acer rubrum*), and black gum (*Nyssa

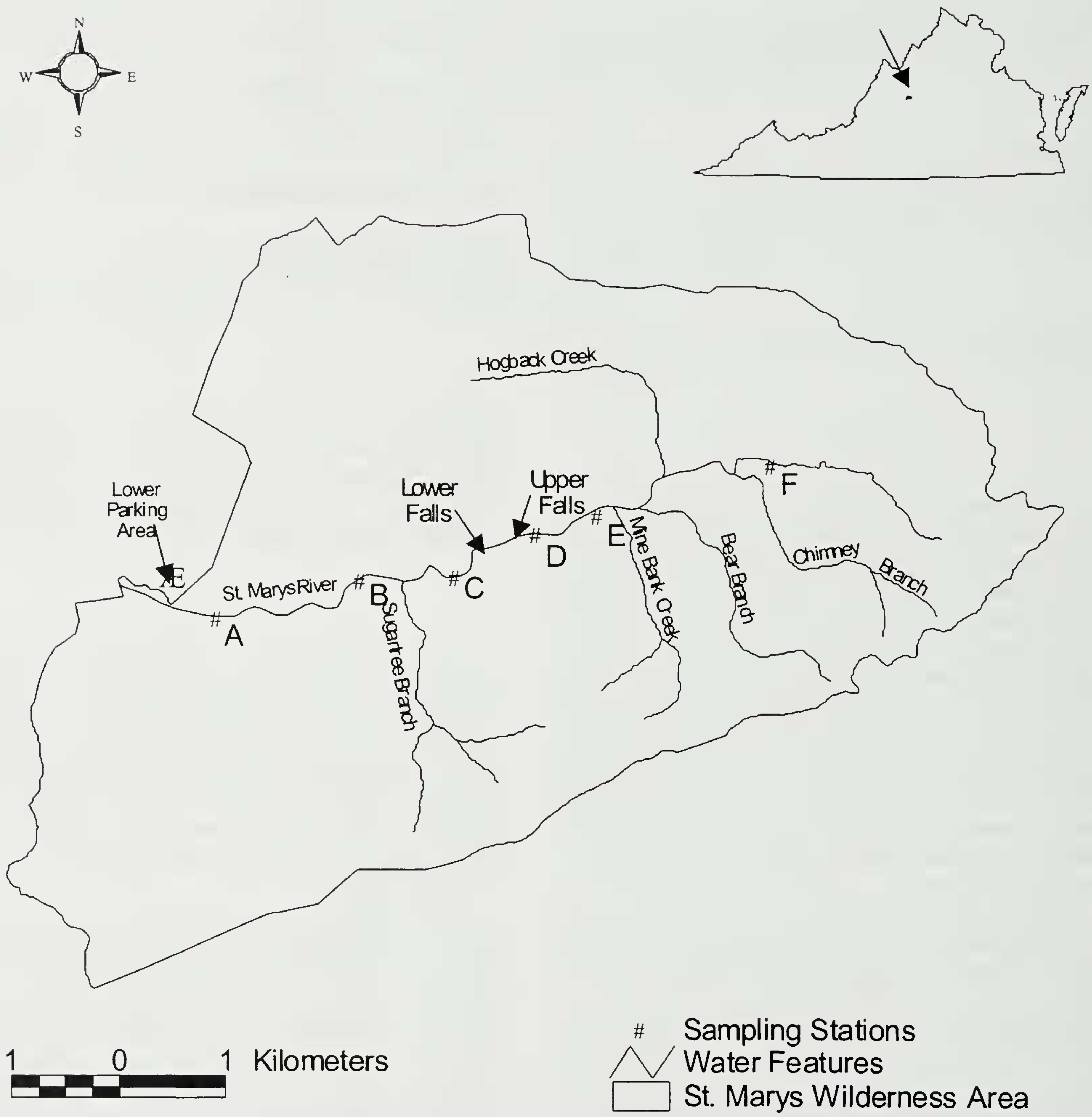

Fig. 1. Department of Game and Inland Fisheries biological sampling stations in the St Marys River, Augusta County, Virginia.

sylvatica). Well drained, sandy loam covers most of the watershed, with the primary soil type being Drall-Hazleton-Leetonia (Hockman et al., 1979). It is considered to be poor, acidic soil. St. Marys has been classified as acidic and has lost the ability to successfully maintain a pH range that will support a diversity of aquatic life (Webb & Deviney 1999). The geology and commercial, scientific, and management history of the study area has been described by Bugas et al. (1999), Bank et al. (1999) and Swartz et al. (1999).

MATERIALS AND METHODS

Surber (1951) collected basic water chemistry in his early St. Marys River study but did not report the method used for pH determination or the collection sites, however, electronic and color comparator methods were available at that time. Trout Unlimited used a color comparator for determination in 1974 (G. D. Schuder, unpublished letter to VDGIF, 1976). Mohn (1980) used a color comparator for pH determinations in 1976. We recently compared readings by the color comparator to samples analyzed electronically at the University of Virginia. Readings were 0.5 to 1.0 units higher than those from the electronic pH meter. Since this difference can span $\pm$0.5 pH units, we left the 1974 and 1976 data uncorrected. Starting in 1986, water samples were collected quarterly and pH was determined electronically as part of the Virginia Trout Stream Sensitivity Study (Webb et al., 1994).

Surber collected twenty 0.09 m^2 samples per month for two years starting in August 1935 (Surber, 1951). Mesh size was 1 mm. Only his June samples were used since collections in later years were made only in June. Surber reported the data in defined taxa with a miscellaneous group for each order. Taxonomic names Surber reported were corrected to current classifications using Merritt & Cummins (1984).

Mohn (1980) described the use of the Carle sampler to collect invertebrates. One sample (0.27 m^2) was collected at each of the six sampling locations (Fig. 1). Mesh size was 1 mm. Sampling sites were located at evenly spaced intervals from the lower St. Marys Wilderness boundary to the headwaters. Total sample area per collection year was 1.6 m^2. Carle (1976) compared his sampler to the Surber sampler and concluded that invertebrate diversity was similar if the surface area sampled exceeded 1 m^2. Carle concluded that his sampler with one run (as opposed to a three run depletion) provided higher invertebrate densities (an average of 31%), although the differences were not statistically significant. Carle documented no species selectivity by his sampler. In our study, identification was to genus or species but taxa were combined to fit those categories reported by Surber for this comparison.

The Shannon diversity index, equitability index, EPT index, and Rapid Bioassessment III protocols were used to evaluate community health as described by Klemm et al. (1990). The EPT index is a total of the Ephemeroptera, Plecoptera, and Trichoptera taxa collected. These three orders are considered to be pollution intolerant and serve as good indicators of community change. Rapid Bioassessment III compares a stream to a reference section that is in good health and involves an integrated analysis of both functional and structural components of the aquatic invertebrate community. For this analysis, the 1936-37 sample was averaged and used as the reference site. Seven metrics comprise the RBP-III: taxa richness, modified Hilsenhoff biotic Index, ratio of scrapers to collector-filterers, ratio of EPT's to chironomids, percent contribution of the dominant taxon, EPT index, and community loss index. Any changes reflect the temporal impacts of acidification.

RESULTS AND DISCUSSION

Water pH declined over time with no values recorded above 6.0 after 1992 (Table 1). Prior to 1988, only one sample had a value below 6.0. Several recent samples have had readings below 5.2. Pre-industrial pH of precipitation in Virginia has been estimated to be from 5.3 to 5.6 (Webb, 1987). In 1996, precipitation pH readings at the Big Meadows water monitoring station in Shenandoah National Park, Madison Co., Virginia averaged 4.4 (US Environmental Protection Agency, 1998). The low buffering capacity of the watershed has resulted in pH readings closely paralleling rainfall pH.

Changes in the invertebrate taxa over the sixty-year period can be grouped into four categories: unchanged, extirpated, declined, and increased. Values of 0.6 individuals m^2 represent the collection of a single individual (Table 2).

Table 1. Range of pH values collected from 1936 to 1996 in the St. Marys River, Augusta County, Virginia.

Year	High	Low
1938	6.9	6.7
1974*	7.0	6.7
1976 (one sample)*	7.0	
1988	6.10	5.20
1990	6.12	5.54
1992	6.07	5.16
1994	5.97	5.51
1996	5.70	5.12

*Values were by colormetric determination. Comparison of this method with later electronic analysis indicates readings are 0.5 to 1.0 units high.

Table 2. Number of benthic macroinvertebrates collected per square meter in the St. Marys River from 1936 to 1998. Renamed original taxa are indicated by the old name in parenthesis. Blank spaces indicate that no indivduals were collected.

TAXA	1936	1937	1976	1986	1988	1990	1992	1994	1996	1998
Oligochaeta	5.4	1.1	3.8	0.0	1.8	3.8	0.0	1.8	16.2	4.9
Crustacea										
Cambarus	7.5	4.8	1.3	0.6	3.1	2.5	1.3	6.2	0.6	0.0
Trichoptera										
Cheumatopsyche/Hydropsych	73.7	26.4	11.3	8.2		1.8	5.6		1.3	2.5
Dolophilodes	60.3	7.5	0.0	3.7			2.5			0.6
Rhyacophila	13.5	7.0	4.4			0.6	0.6	3.8	3.1	0.6
Brachycentrus	0.5	2.2			8.2	6.9	0.6			1.8
Misc. Trichoptera	19.9	3.2	20.7				10.7	9.4		12.5
Plecoptera										
Leuctra, Alloperla etc.	15.6	12.4	331.0	75.1	55.1	171.1	521.9	402.2	282.1	258.2
Peltoperla	7.5	1.1	22.5	0.6	0.6			1.3	5.1	30.1
Perla & Acroneura	23.1	17.2	4.9	1.3	1.3	0.6	3.1		1.8	
Pteronarcys	4.8	1.6	1.3							3.1
Nemoura	5.9	0.5								
Misc. Plecoptera	1.1		104.5	3.1	4.9	3.1	27.5	6.2	10.7	11.3
Odonata										
Lanthus	0.5									1.3
Misc. Odonata	0.5		2.5				1.8	1.3	1.3	0.0
Ephemeroptera										
Stenonema	30.7	16.1	12.5	1.3	1.3			8.2	3.8	3.1
Baetis & Pseudocleon	32.3	30.7	19.4	6.9		10.7	0.6	8.2	4.4	6.9
Paraleptophlebia	21.0	55.4	0.6							
Epeorus (Iron)	80.7	33.4	0.6							
Ephemerella	74.8	17.2	0.6						1.3	0.6
Isonychia	1.1		0.6						0.6	
Misc. Ephemeroptera	0.0	2.2			5.6		3.1	1.3	0.6	1.3
Megaloptera (Neuroptera)										
Nigronia	5.7	6.5	1.3		4.4		4.4	8.7	1.3	5.6
Coleoptera										
Elmidae (Parnid)	1.6	1.6	14.4	2.5	5.6	1.8	1.3	5.1	1.8	13.8
Psephenus	0.5	1.1								
Misc. Coleoptera	2.2	2.7								
Diptera										
Atherix	5.4	13.5								0.6
Chironomidae	61.9	35.5	281.9	35.1	128.3	164.6	167.9	183.2	303.4	642.4
Hexatoma (Erioica)	5.4	7.5	9.4							
Simulium	15.6	11.3	14.4		1.3	0.6	52.5	2.5	4.4	20.4
Antocha	2.7	1.6	3.1	2.5	0.6					
Misc. Diptera	3.8	1.6	0.0		0.6		5.1	5.6	0.6	8.7
Miscellaneous invertebrat	0.5	1.1	0.0	0.6	0.6	3.1		0.6	3.1	8.1
TOTAL ABUNDANCE	585.7	323.9	867.0	141.5	224.8	371.3	810.6	655.6	647.8	1038.0
NUMBER OF TAXA	32	29	23	13	19	13	17	17	20	22
EPT TAXA	17	16	14	8	9	7	10	8	10	13
DIVERSITY (Shannon)	3.94	3.96	2.66	2.12	2.02	1.65	1.69	1.67	1.69	1.8
EQUIBILITY (e)	0.72	0.79	0.35	0.46	0.26	0.3	0.23	0.23	0.2	0.18
% Biological Cond. Score	Averaged		71	48	38	38	57	52	52	52

Unchanged Taxa

Taxa that were unchanged showed considerable variation but no apparent trend in abundance (Table 2). These include: Oligochaeta, *Cambarus* (crayfish), *Brachycentrus* (American grannon), *Peltoperla* (roachlike stonefly) *Isonychia* (brushlegged mayfly), *Nigronia* (fish flies), *Elmidae* (riffle beetles), and *Simulium* (black fly). Miscellaneous Trichoptera, Odonata, Ephemeroptera, and Diptera showed no apparent trends. Smith et al. (1990) and Simpson et al. (1985) reported elmids (Coleoptera) to be acid tolerant but that they decline when pH falls below 6.0. Townsend et al. (1983), however, found no correlation between the abundance of elmids and the pH of streams in England.

Declined Taxa

Declining taxa showed varying responses. In all cases numbers collected between 1976 and 1998 were fewer than observed in the 1936 and 1937 samples (Table 2). Trichoptera taxa included *Cheumatopsyche/Hydropsyche* (common netspinners), *Dolophilodes* (fingernet caddisfly) and *Rhyacophila* (green sedge). *Dolophilodes* were collected only three times since 1976. Peterson & VanEeckhaute (1992) reported that *Rhyacophila* were found in acidic streams but *Dolophilodes* were not observed in streams when summer pH was less than 5.9.

Considering stoneflies (Plecoptera), *Perla/Acroneuria* (common stonefly) and *Pteronarcys* (giant black stonefly) have declined in the river with *Pteronarcys* being collected only in 1936, 1937, 1976, and 1998. Griffith & Perry (1992) collected *Acroneuria* in West Virginia streams when pH was 7.5, but not in streams below 6.2.

Mayflies (Ephemeroptera) showed the greatest decline in the St. Marys River, similar to other literature reports on this order. *Stenonema* (March brown), *Baetis/Pseudocloen* (small minnow mayfly and skimmer) and *Ephemerella* (sulphur) were very abundant in 1936 and 1937 but have declined substantially, with *Ephemerella* collected only three times from the last eight samples. Feldman (1986) observed that *Stenonema* had greater tolerance to acidity than *Ephemerella,* and that *Epheme-rella* was low or absent in low alkalinity streams. The limiting pH for *Ephemerella* is 5.5 to 5.7 and for *Baetis* is 5.7 to 6.0 (Peterson & VanEeckhaute, 1992). Fiance (1978) observed that *Ephemerella funeralis* was absent when pH was <5.5. Smith et al. (1990) observed that *Baetis* occurred only when pH was >5.4.

Extirpated Taxa

Some taxa have been extirpated from the St. Marys River. The stonefly (Plecoptera) *Nemoura* (nemourid broadbacks) and the Coleoptera *Psephenus* (water penny) have not been collected since 1936 and 1937. The mayflies *Paraleptophlebia* (dark blue quill) and *Epeorus* (quill gordon) were last collected in 1976 and their numbers were substantially reduced from the 1936 and 1937 collections. Peterson & VanEeckhaute (1992) reported that the limiting pH for *Epeorus* was 5.7-6.0. Lasier (1986) observed that *Epeorus* abundance was correlated with stream pH. Feldman (1986) also observed that *Paraleptophlebia* and *Epeorus* were absent in low alkalinity streams.

The dipteran, *Antocha* (crane fly) was last collected in 1988 but prior to that its numbers were stable over the years. *Atherix* (watersnipe fly) has not been collected since the 1936 and 1937 samples except for one individual in 1998. *Hexatoma* (crane fly) has not been collected since 1976.

Increased Taxa

Only three taxa have increased in abundance (Table 2). Two of these were Plecoptera: *Leuctra/Alloperla* (rolledwinged stonefly/green stonefly) and miscellaneous Plecoptera. Increased abundance of *Leuctra* in acidified waters is one of the most documented changes observed (Fiance, 1979; Arnold et al., 1981; Townsend et al., 1983; Kimmel & Murphy, 1985; Simpson et al., 1985; Lasier, 1986; Smith et al., 1990).

The abundance of Chironomidae (midges) has increased at least five fold since the 1936 and 1937 collections. Chironomidae increase is also a well-documented change in acidified waters (Hall et al., 1980; Townsend et al., 1983; Kimmel & Murphy, 1985; Lasier, 1986).

Increased abundance of these taxa is the result of several factors. The first is the resistance to low pH, as reported in the above studies. A second factor may be reduced competition from taxa that are not tolerant to low pH. As these acidophobic taxa are reduced in numbers, increased niches may be available for acidophilic taxa.

Community Structure

Total numbers of individuals collected have generally increased, although the lowest abundance occurred in 1986 (Table 2). The increase may be an artifact of the different sampling methods. However, most of this increase and shift occurred in the acid tolerant taxa Chironomidae and *Leuctra/Alloperla.* In the 1930s, these two taxa together comprised only 10-20% of the community but now comprise around 90%. The low abundance in 1986 may reflect the impact of a major flood in 1985. A flood also occurred in 1937 before Surber's sampling that year and may have caused the decline from 1936.

The numbers of taxa were highest in 1936-37, slightly lower in 1976, and have held steady since 1976 (Table 2). Much of the reduction in numbers of taxa collected has occurred in the EPT taxa. Ephemeroptera have been well documented as declining in species abundance and richness with a decrease in pH (Mackay & Kersey, 1985; Burton & Allan, 1986; Peterson & Van Eeckhaute, 1992; Kobuszewski & Perry, 1993).

Shannon diversity index values also declined (Table 2). Highest values were in 1936-37 at 4.0. Diversity continued to decline from 1976 through 1988. Since 1988, all diversity values have been below 2.0 with a slight improvement in 1998. Unpolluted waters generally have values between 3 and 4 (Klemm et al., 1990). Values observed in 1936-37 reflect a healthy environment that has since declined over time.

The equitability index was highest in 1936-37 and declined since those samples were taken (Table 2). Unpolluted waters have values above 0.5 whereas stressed waters have values 0.3 or lower (Klemm et al., 1990). Since 1988, the system is rated as being stressed. Even though diversity increased slightly in 1998, the equitability index declined to its lowest value that year. Similar declines in species richness, diversity, and equitability have been observed in other Appalachian and Adirondack acidic streams (Hall et al., 1980; Arnold et al., 1981; Burton et al., 1982; Kimmel, 1985; Simpson et al., 1985; Feldman, 1986; Peterson & VanEeckhaute, 1992).

Bioassessment scores declined from average values in 1936-37 (Table 2). The decline was first observed in 1976. That year (value of 71) would be rated as slightly impaired by Plafkin (1989) compared to the 1936-37 sample. Values after 1976 declined further, the lowest values being observed in 1988 and 1990 at 38. In 1992, the percent comparability to the reference score was 57, giving a rating of slightly impaired. All other years since 1976 (except 1992) are rated as moderately impaired.

Our documented changes in the macroinvertebrate community in the St. Marys River provide the first documented impact of temporal changes in acidification on a southeast U.S.A. stream. The observed changes in the invertebrate fauna are consistent with those reported in the literature for streams with low pH. Taxa such as *Epeorus*, *Ephemerella*, *Paraleptophlebia,* and *Stenonema*, which have been identified as being acid intolerant, have declined in the St. Marys River. Acid tolerant taxa such as *Leuctra* and Chironomidae increased. Community structure and complexity declined as a result of the stress of anthropogenic acidification. Our data clearly demonstrate that biological degradation as a result of acid deposition has occurred in St. Marys River and may reflect conditions in the southern Appalachian Mountains.

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